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SEPTEMBER, 1943
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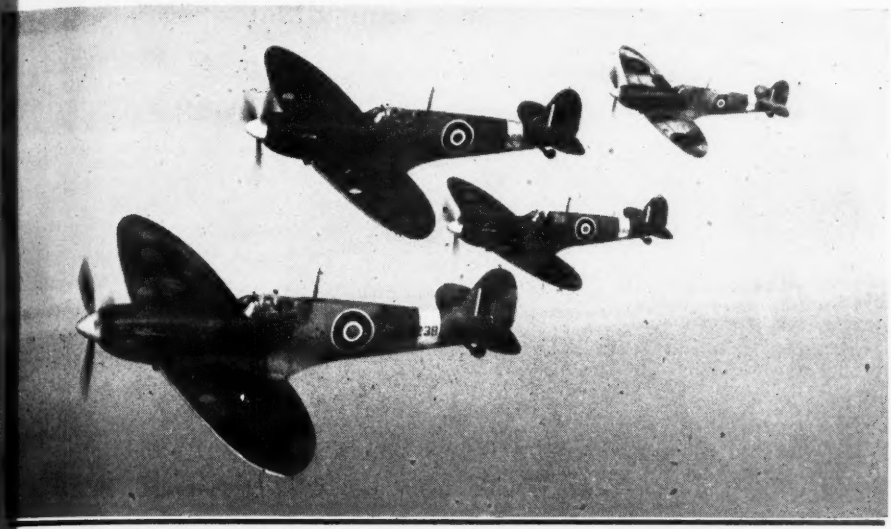

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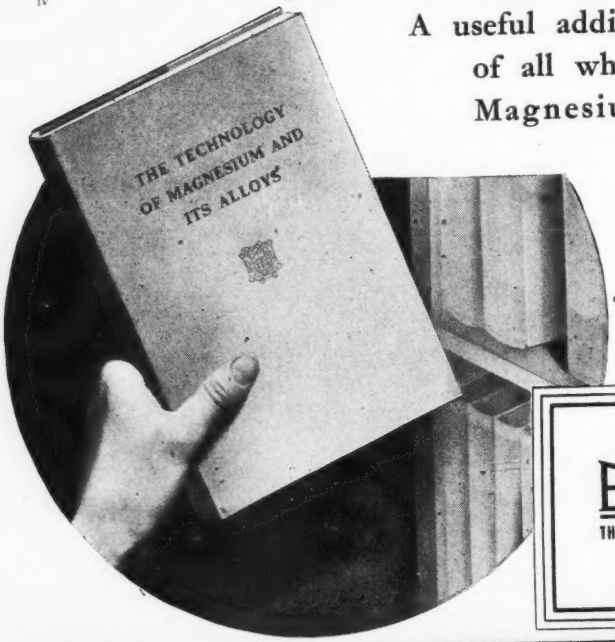

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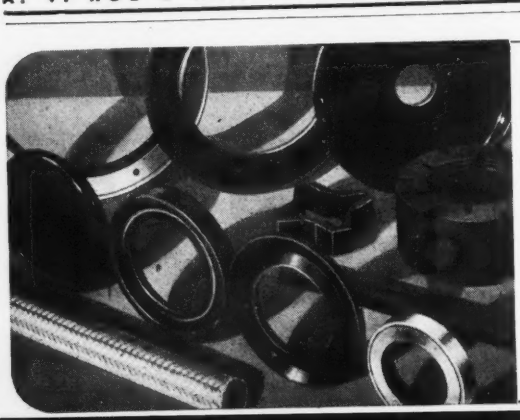

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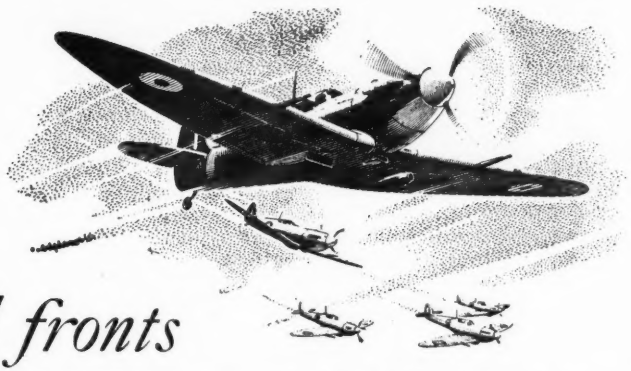

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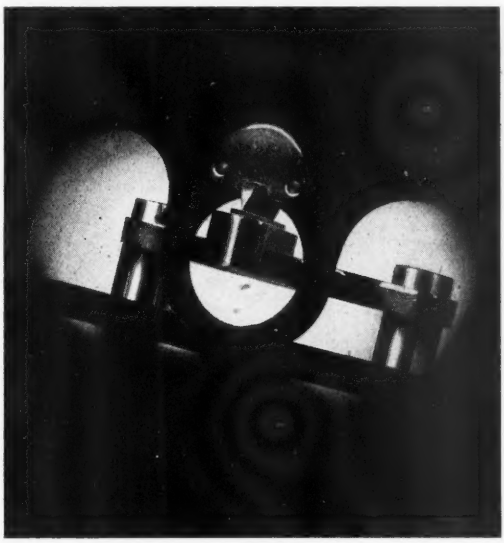

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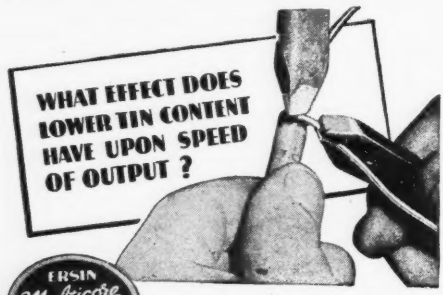

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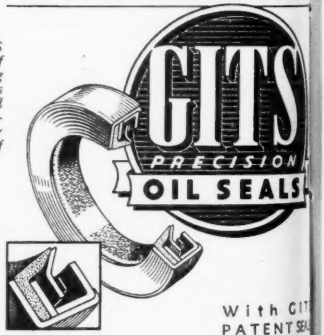

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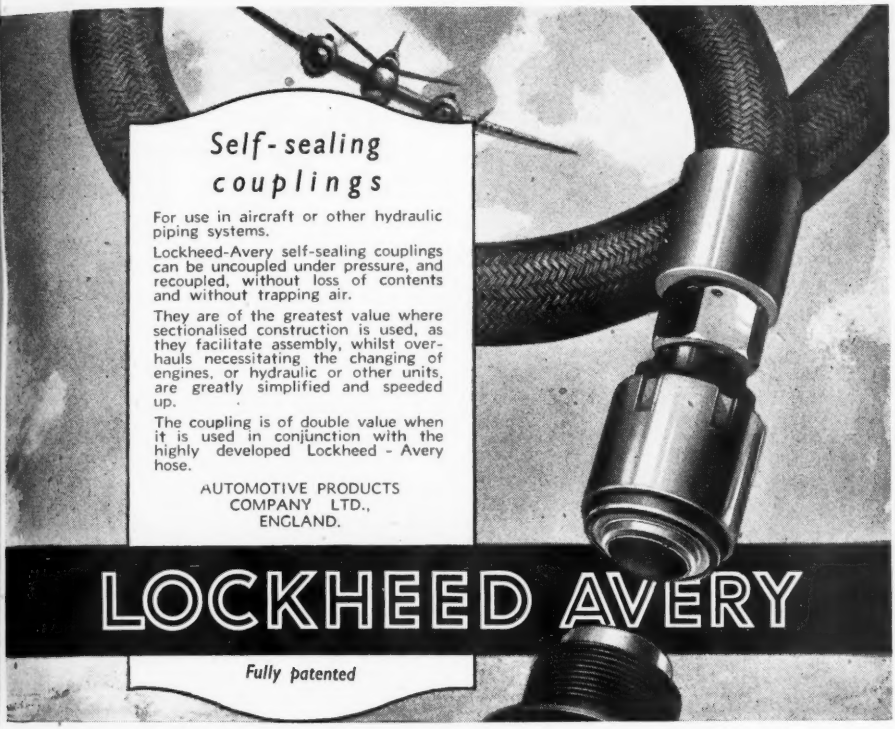
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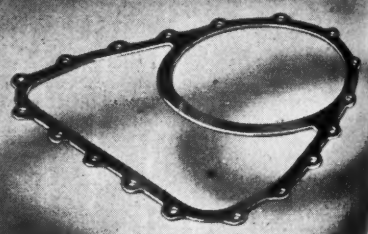

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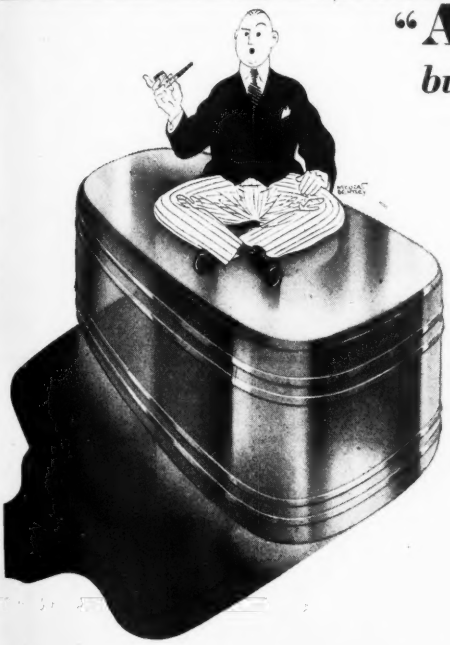

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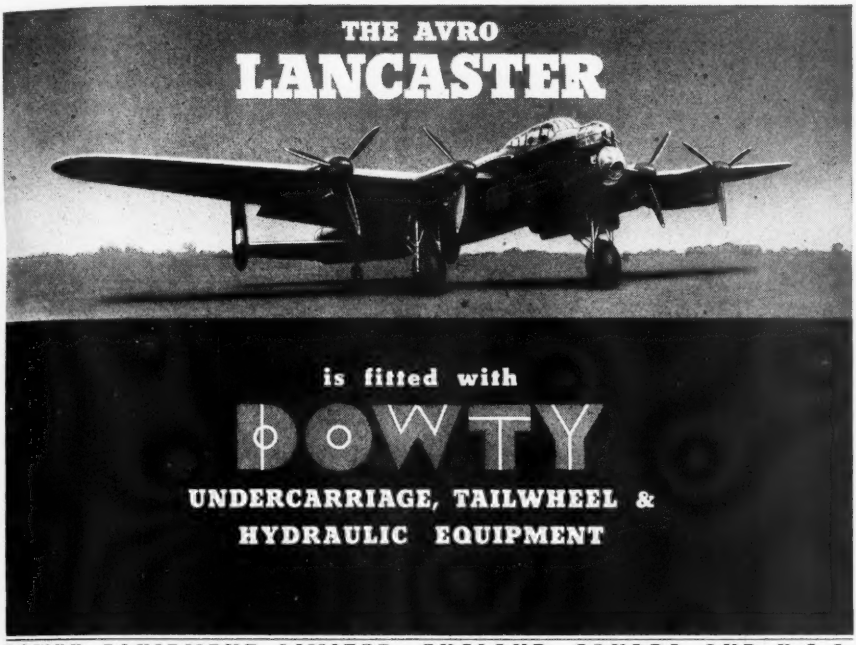

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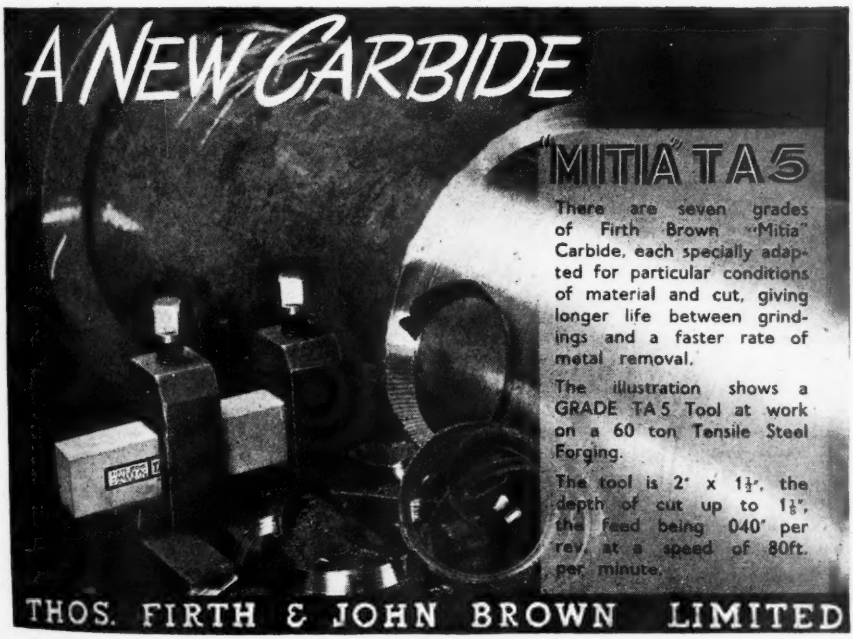
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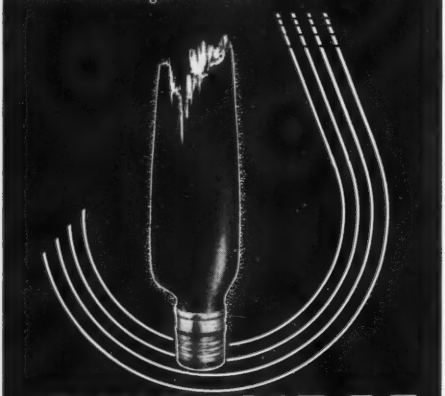

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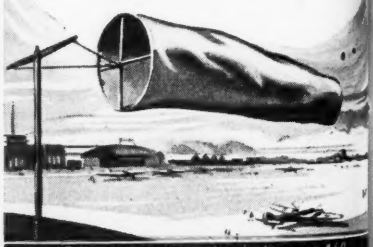

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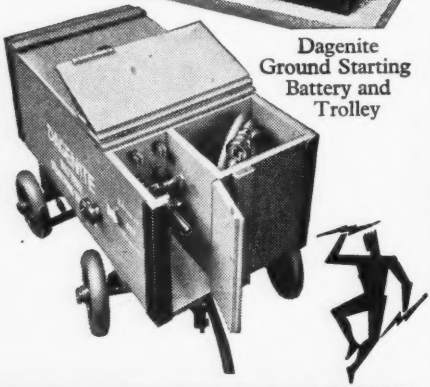

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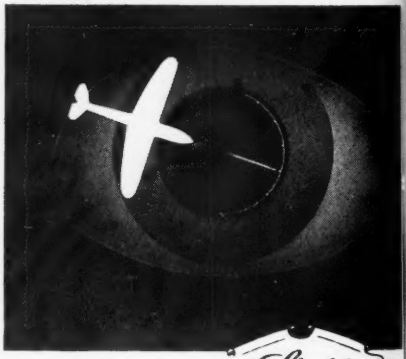

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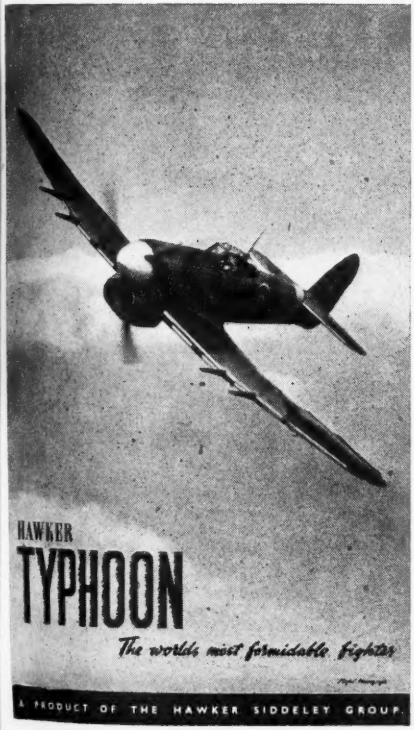

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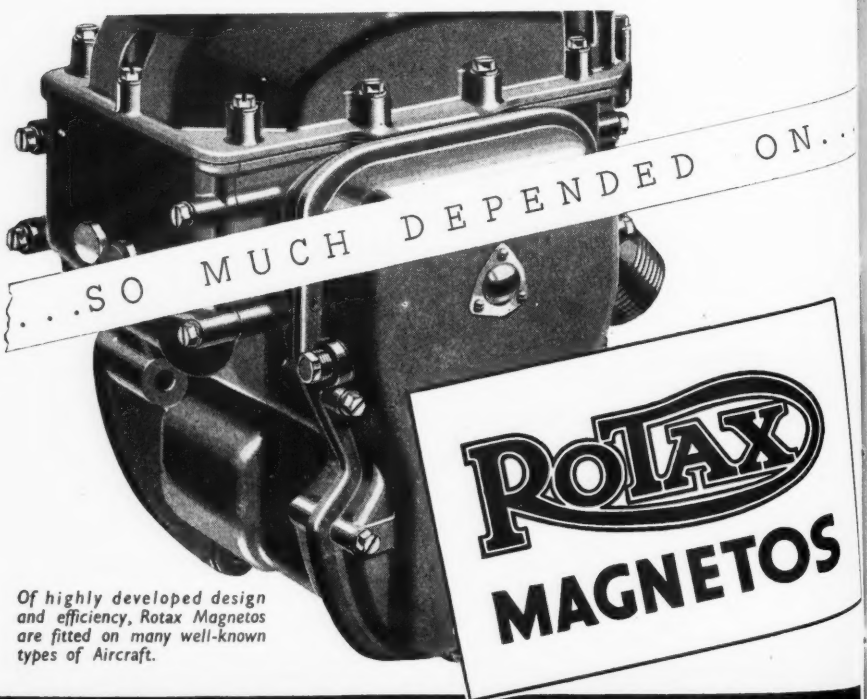

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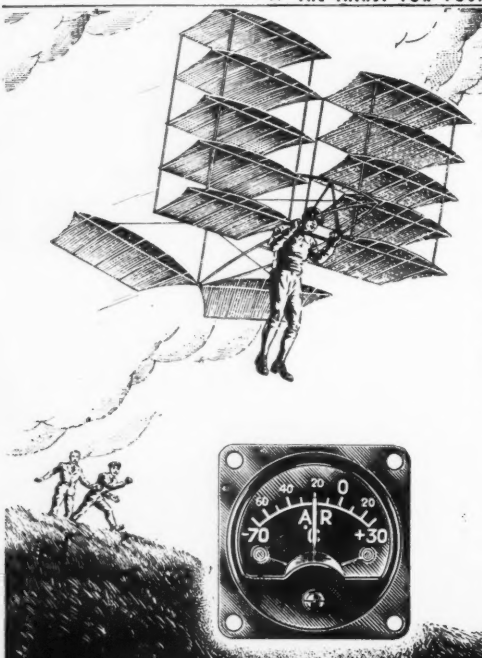
☆ THE THIRST FOR POSITIVE KNOWLEDGE ☆



The Glider

Legend tells of many a brave man who devoted his lifetime in the effort to gain positive knowledge of controlled flight. Berblinger, 'the Flying Tailor of Ulm,' trusted his life to a flying suit of his own invention, escaping with no worse effects than a dip in the Danube. Octave Chanute, in the last century made over 1,000 glides in the apparatus illustrated here, which is said to have encouraged the Wright Brothers in their experiments. Positive knowledge of many aspects of flight is to-day provided to pilot and aircrew by Weston Instruments which guide and inform from take-off to landing.

Weston Aircraft INSTRUMENTS

POSITIVE KNOWLEDGE—FROM TAKE OFF TO TOUCH DOWN

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THE ROYAL AERONAUTICAL SOCIETY

WITH WHICH IS INCORPORATED THE INSTITUTION OF AERONAUTICAL ENGINEERS

SEPTEMBER, 1943.

Library Opening.

The Library is normally open on Mondays-Fridays inclusive from 9.30 a.m.—5 p.m. In addition it will also be open on Saturday afternoons from 2.30 p.m.—5.30 p.m. until further notice and as long as the attendance justifies it.

Associate Fellowship Examinations.

Candidates for the December, 1943, Examinations are reminded that entries must be received by the Secretary not later than September 30th, 1943. Entry Forms may be obtained from the Secretary.

Graduates' and Students' Section.

The following two meetings have been arranged and these will be the last of the present Session :—

15th September, 1943 (Wednesday), at 4, Hamilton Place, at 7.30 p.m.—"Aircraft Woods," by Mr. Nelhersh, of the Airscrew Company.

22nd September, 1943 (Wednesday), at 4, Hamilton Place, at 6.30 p.m.—Informal Talk, by Sir Frederick Handley Page, C.B.E., F.R.Ae.S.

Changes of Address.

The attention of members is particularly called to the amount of work placed upon the heavily depleted staff by members who frequently change their addresses. It would considerably help the work of the office if members would give some permanent address to which Journals, etc., could be sent.

Owing to the extreme shortage of paper it will not be possible in the future to replace any Journals which have been lost in the post due to such changes of address

Acknowledgments.

The Council acknowledge with grateful thanks the following gift :—

Back numbers of Journals and Magazines from Mr. C. G. Grey, Founder Member.

Advertisements.

The fact that goods made of raw materials in short supply, owing to war conditions, are advertised in the Journal should not be taken as an indication that they are necessarily available for export.

Election of Members.

The following members have recently been elected:—

Associate Fellows.—Vernon Arthur Moore Hunt (from Graduate), Desmond John Tynan-Bird (from Associate).

Associates.—James Stuart Backhouse, Charles Henry Fielding, Alexander Syme Lockhart, Norman Thomas Luce, Roland Topham.

Graduates.—Edward Brown, Aulay William Watson.

Students.—Derek Harold Spencer, John Prynne Uffen, J. E. Vargas.

Additions to the Library.

Pamphlets in italics with location reference following in brackets.

Books marked * or ** may not be taken out on loan.

B.b.21.—*Helicopters for Use in Canada. Canadian Pacific Air Lines.* (*Press Release.*) 1943. (Y.3.ii.H.)

B.c.63.—*Shall we ever Fly like Birds?* (*Article on Ornithopters.*) *Frank Illingworth.* "*The Morris Owner,*" *April 25th*, 1941. (Y.10.a.9.)

B.f.87.—*Les Oiseaux.* (*Encyclopédie par l'Image.*) *Librairie Hachette.* 1927. (Y.10.b.4a.)

BB.d.32.—Understanding Aircraft Components, by Question and Answer. W. Hazell. English Universities Press. 1943. 2/6.

*C.d.147.—*Notes on Airships for Commercial Purposes. Air Ministry. H.M.S.O.* 1918. (PC.1.c.4a.)

*D.a.C.19.—*Civil Aviation in Canada*, 1941. *Dominion Bureau of Statistics, Ottawa.* 1943. (File Case.)

D.b.193.—*Our Future Lies in the Air. Peter Masefield.* (*Article in* "*The Imperial Review,*" *Aug.*, 1943.) (Y.6.b.25.)

D.f.39.—*Air Travel Insurance. Canadian Pacific Air Lines.* (*Press Release.*) 1943. (Y.12.a.13.)

E.d.18.—Aircraft Layout and Detail Design. Newton H. Anderson. McGraw Hill Book Co. 1941. 21/-.

*EE.b.72-76.—*Ministry of Aircraft Production Official Reports: Jumo 211A; Jumo 211B; Bench Tests of Jumo 211D; Jumo Fuel Injection Pumps; Modifications to Jumo 211.* (*Stencils, with photographs and drawings attached.*) 1943. (Y.3.iii.19-23.)

G.f.29.—*Fluxes for Electrical Work.* (*Report TE.* 346.) *Fry's Metal Foundries.* 1943. (Y.13.b.8.)

L.d.93.—*The Air Navigator's Stars. L. R. Glegg. Air League of the British Empire.* 1943. (PL.1.b.7.)

L.d.94.—Nicholls' Concise Guide for Second Mates to the Local Marine Board Examination. F. W. Maxwell. James Brown, Glasgow. 1925.

L.f.11.—Modern Compass Adjusting. John C. Gillie. Allen and Unwin. 1943. 3/6.

**R.b.241-245.—*Four numbers of* "*The Mirror of Literature, Amusement and Instruction,*" *with items of aeronautical interest, as under*:—

Sept. 13, 1823: Article on Balloons and Parachutes.

Nov. 29, 1823: Description of monument to Pilâtre de Rozier, near Boulogne.

May 9, 1829: Humorous verses: "The Air Balloon." (In Laudem Bullæ Aero-nauticæ.)

June 20, 1829: Letter from "P.T.W." describing a balloon ascent with Mr. Green, from Rotherhithe.

**R.b.245.—*Balloon ticket for ascent in Nadar's* "*Le Géant*" *at Cremorne Gardens, autographed by Nadar.* (1863.)

**R.f.87.—The First Century of Flight in America. Jeremiah Milbank, Jr. Princeton University Press, U.S.A. 1943. $2.75.

RR.118.—L'Aviation pour Tous. André Lainé. Librairie Delagrave. 1927.

*S.a.133.—Four military manuals (bound together), as under:—
Notes for Artillery Observers (1st Ed.).
Notes from the Front, Part III (Feb., 1915).
Notes on Platoon and Company Drill (Sept., 1916).
Physical Training Tables and Games (1918).
War Office and R.A.F., 1914-1918.

S.d.84.—Imperial Defence. Major-Gen. H. Rowan Robinson. Frederick Muller. 1938.

S.e.67.—War in the Air. David Garnett. Chatto and Windus. 1941. 7/6.

T.b.85.—Some Still Live. (An Airman's Adventures in the Spanish War.) F. G. Tinker. Lovat Dickson. 1938.

T.b.86.—Our Atlantic Attempt. H. G. Hawker and K. Mackenzie Grieve. Methuen and Co. 1919.

*X.a.51.—Aircraft Handbook. Fred H. Colvin. McGraw Hill Book Co. 1942. 35/-.

*X.b.145.—The Aeroplane Production Yearbook and Manual. Ed. by Group Capt. G. W. Williamson. Paul Elek, Ltd. 1943. 40/-.

J. LAURENCE PRITCHARD, *Secretary and Editor.*

WORK IN AN EXPERIMENTAL SEAPLANE TANK.

By Leonard Smith, Grad., R.Ae.S.

Fundamentals.

In addition to the usual aerodynamic and structural problems the seaplane designer has a number of problems to solve which are associated with the behaviour of the seaplane on the water. The operation of a seaplane on the water is well known and in these days accepted as a matter of course. However, behind these apparently easy operations there lies a background of continued effort and development.

The mathematical treatment of problems associated with bodies moving in and between two dissimilar fluids is complex and although some work has been done on seaplane take-off it has not reached a stage of general usefulness. The designer has, therefore, to resort to other means for the solution of such problems. Three courses are open—to follow the dictates of an experimental seaplane tank, build a flying model capable of carrying personnel or to work on the experience gained from past designs. Usually a fusion of these three courses takes place. The designer who works on past experience alone tends, by the restraining influence of conservatism, to impede progressive development, while a poor interpretation or limited understanding of model results may produce an unsatisfactory seaplane. The use of a flying model has become more widespread, but the use of such a model would only appear justified when marked changes have been made in the general design.

On the grounds of cheapness, quickness and continued development the tank scores every time.

A seaplane is any aircraft which operates from the water and can, in general, be put into two main groups—the flying boat or boat seaplane and the float seaplane. Only the first will be discussed.

The hull must be large enough to carry the weight of the complete flying boat and at the same time possess a large reserve of buoyancy to meet conditions set up in heavy seas. In the case of a passenger boat ample accommodation must be provided for both crew and passengers. The hull top shapes are governed by aerodynamic requirements, but the bottom is specially designed to enable the boat to take-off and alight on the water in the most efficient manner.

Fig. 1 shows the side elevation, half plan and some half sections of a typical modern British flying boat hull.

The hull can be divided into three main portions—forebody, afterbody and tail.

The forebody and afterbody are separated and displaced by a step, called the main step. This step, in its simplest form, consists of a transverse break in the continuity of the longitudinal bottom lines. The hull lines shown incorporate a veed or pointed main step, which has been a special feature of Short hulls for a number of years.

The afterbody is separated from the tail by a second or rear step. The step shown is the pointed or knife-edged type which was first used by Short's on the "Sunderland."

The tail portion carries the tail unit and gun turret on a military boat.

The bottom is separated from the hull sides by a hard line or chine which extends from the bows to rear step, and the transverse bottom sections are vee shaped as shown on the half sections.

Having described the essential features of a hull, it is necessary to explain, briefly, their various functions and developments.

The minimum flying speed of a fairly large flying boat is in the region of 80 m.p.h. Thus the boat must be capable of travelling on the water at high speeds, to leave it, and then make contact again at the end of the flight. The time taken to travel on the water before the flying boat becomes air-borne must be as short as possible and should not exceed 60 seconds. The bottom shapes of the hull have, therefore, been developed to enable the flying boat to become air-borne and water-borne in the most efficient manner.

It will have been noticed from Fig. 1 and the subsequent description that the bottom shapes do not resemble normal ship or canoe bodies which, by virtue of their clean shape, lend themselves to efficient aerodynamic performance.

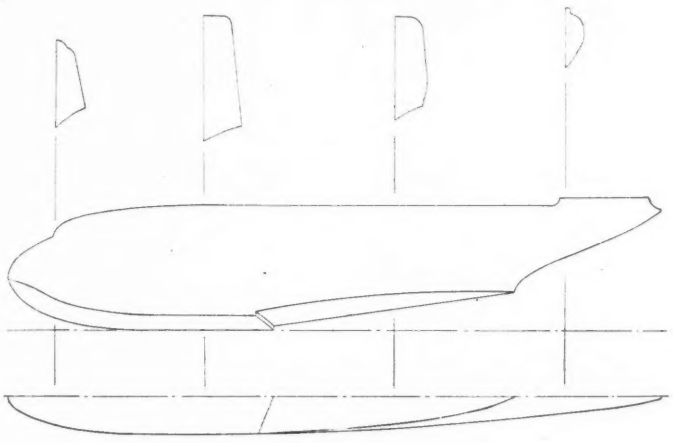


FIG. 1.

Lines of typical hull.

Canoe bodies do not lend themselves to really high speed running on the water because a large amount of power is required to drive them. The reason for this is that they show little tendency to rise and so reduce wave making and skin friction resistance. It can be shown that, with the engine powers available to-day, any flying boat incorporating a canoe shaped bottom would never leave the water. Another aspect to be considered is the dynamic longitudinal stability at high speeds. The canoe body does not possess any marked degree of stability at high speeds and it is sufficient to say that the stability of the conventional bottom is sometimes unsatisfactory. Tests made on streamlined hulls show that the hull sinks into the water and that the whole body becomes swamped. Alighting tests show that such a hull would sink straight into the water, and in full scale this would mean a wrecked flying boat.

Fast motor boats are fitted with a bottom which promotes rise from the water and hence skimming or planing action with the minimum of power. On very fast boats it is customary to fit one or more steps to improve the running efficiency. Malcolm Campbell's " Blue Bird " was fitted with a single step and was almost air-borne when travelling at speed.

Speaking in broad terms, speed for a given power is associated with the ability to rise from the water.

Because a flying boat must be capable of leaving the water it is not surprising to find that the bottom shapes resemble those of a fast motor boat.

During take-off the seaplane passes through three distinct stages of operation:

(i) Displacement.
(ii) Two-step.
(iii) Planing.

This order is reversed on alighting.

The displacement stage embraces low speed running, such as taxying and the forces on the hull compare with those found on craft like low speed motor launches.

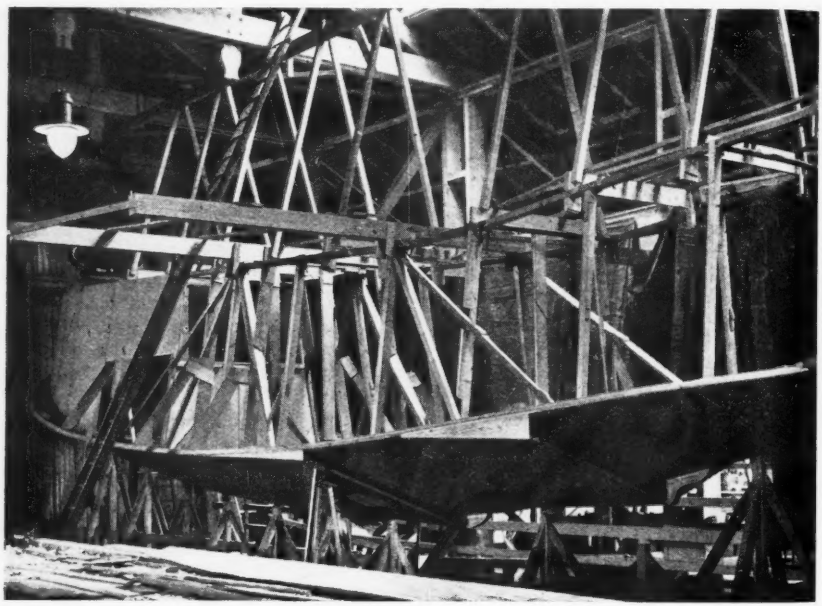


FIG. 2.
Cromarty.

In the two-step stage the seaplane passes from the displacement to the planing condition and on normal hulls these conditions produce a maximum water resistance. This resistance is called the hump resistance and occurs at approximately one-third of the take-off speed. On well designed hulls the hump resistance does not exceed one-fifth of the weight of the seaplane.

When true planing is reached the hull under the influence of wing and planing action gradually rises from the water until it is air-borne.

The object of a main step is to promote a reduction in resistance, but it should not be supposed that this is its sole purpose, because the running behaviour of the hull is influenced by its location.

When a speed of, say, 20 knots is reached the water running under the bottom passes over the main step and impinges on the afterbody at some distance behind the step. With increase in speed the dry region extends farther back along the

afterbody until only a small area is wetted. The immediate result of this is to reduce the resistance and promote planing and bodily rise from the water.

The rear step forms a suitable ending to the planing bottom as it prevents water from rising and striking the tail and surrounding structure. This step, also, assists in the longitudinal stabilization of the hull at high speeds.

Attempts have been made to eliminate steps but results have shown that the resistance exceeds the available airscrew thrust and that the hull is uncontrollable at high speeds.

The chine keeps the water thrown aside by the hull from rising to extreme heights. Any attempt to eliminate chines results in the hull being swamped with water and, apart from the excessive resistance, produces an impossible take-off.

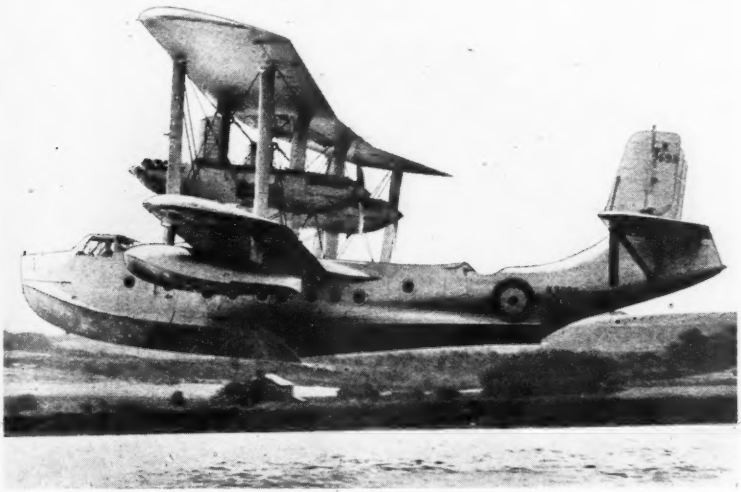


FIG. 3.
Singapore III.

AERODYNAMIC ASPECT.

It is obvious that the fitting of a planing bottom produces an air resistance which exceeds that of a corresponding streamlined body. Therefore, once airborne, the bottom of the hull takes on a parasitic role and, as such, provides an additional problem to the seaplane designer. It has been shown that, at the present time, a planing bottom possessing steps and chines is a necessity and, therefore, the designer is forced to consider very carefully any changes to the bottom which, while improving the air performance of the hull, may produce an unsatisfactory water performance.

In recent years, with the advent of retractable undercarriages on landplanes, the seaplane designer has been forced to pay more attention to the aerodynamic aspect of hull design.

The following remarks deal with some of the attempts made to "clean-up" the hull.

Fig. 2 shows the " Cromarty " flying boat under construction about 20 years ago. The sharp transverse break of the rear step is clearly shown. This source of increased air resistance was partially eliminated by a fairing behind the step as shown on the "Singapore III," Fig. 3.

The introduction of the knife-edged type rear step as found on the "Sunderland," Fig. 4, represents the present limit of development. The use of such a step has

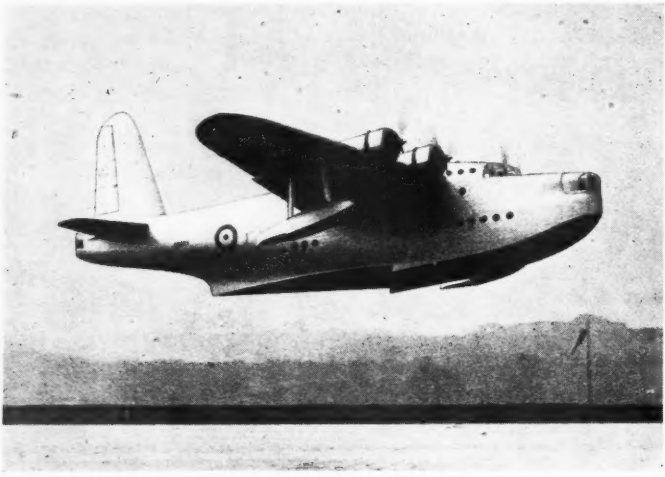


FIG. 4.
Sunderland in flight.

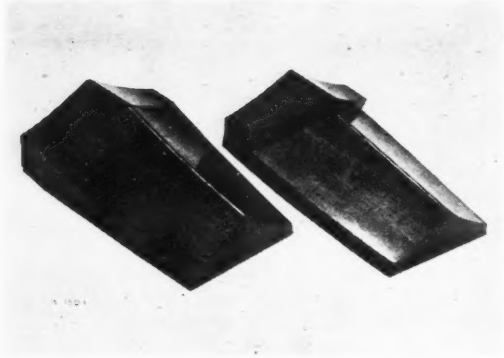


FIG. 5.
Step models.

made it necessary to cut away the "dead-wood" at the tail because this type of step throws up a jet or roach of water which, if allowed to strike the tail, would impede the take-off.

The main step is critical to marked changes but attempts have been made to reduce the air resistance of this step. The introduction of the veed or pointed

form came from hydrodynamic considerations but it does tend to reduce the air resistance when compared with an equivalent transverse step because air can flow in at the chine and relieve some of the turbulence.

A recent aerodynamic improvement has been made by Short's in main step design. This improvement has been achieved by adding behind the step a permanent fairing. Fig. 5 shows a model of a normal Short step together with a model of the modified step to the same scale. The addition of the fairing has been found to increase the top speed of a fairly large flying boat by approximately 5 m.p.h. The fairing also simplifies construction and maintenance.

The fairing is critical to curvature and length. A generous fairing makes the flying boat longitudinally unstable at high speeds on the water. With a well designed fairing the behaviour of the boat is satisfactory, and, under some conditions, the resistance is reduced. It has been found that the length of the fairing should not exceed four times the depth of the step for a satisfactory water performance. In full scale a small break or step is left at the end of the forebody in order to ensure that there is a sharp break at the commencement of the fairing. This would appear sound because water tends to cling to surfaces which are united by a small curve or knuckle.

Retractable fairings of similar form have been tried in full scale but they become fouled with mud and weed, which restrict operations.

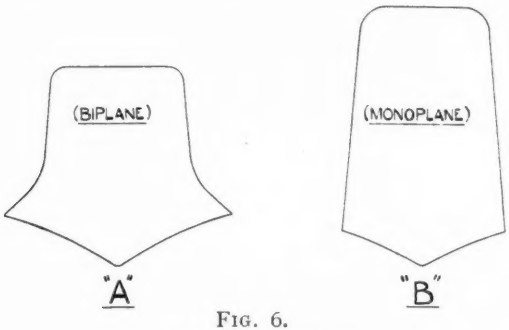


FIG. 6.
Hull cross sections.

In the days of limited engine powers the taking off of a seaplane was sometimes impossible, especially on calm days. Thus the hulls were provided with plenty of planing bottom area which made itself evident in the wide beams and flares. Such hulls possessed high air resistances and high structure weights. Fig. 6 (A) shows the cross section of such a hull.

With the advent of greater engine powers and flaps it was found possible to reduce the hull beam. During the past few years the beams of hulls have been gradually getting less for a given weight of boat. This beam reduction has resulted in an aerodynamic improvement and saving in structure weight. Fig. 6 (B) shows the cross section of a fairly modern hull.

The use of the vee bottom is almost universal.

This section reduces alighting shocks by reason of its gradual entry into the water on touch-down and, also, provides a good path for the water thrown aside by the hull. The old practice of giving the vees a great degree of curvature to reduce wave heights is gradually going and the modern hull possesses only slightly curved vees in order to improve the air performance of the hull.

The bow shapes of the hull must be designed to meet rough water conditions and any aerodynamic shapes incorporated to provide a better " entry " in the air must be treated with reserve.

Opinion varies on the detail design of hull forms, as seen by the various type in existence, but it would seem in these days that the best form is one which ha simple shapes and which performs its water operations in a manner considere satisfactory when regard has been paid to any aerodynamic refinements whic have been made.

Growth of Tank Testing.

The experimental seaplane tank owes its being to the ship tank, introduce by William Froude in 1872. The first man, however, as far as is known, wh used models to determine the behaviour of ships was Frederik Henrik Chapman Born of English parents living in Sweden, Chapman published in 1775 a paper o ship design in which he described his model work.

Fig. 7 shows a diagrammatic arrangement of Chapman's "tank" whic consisted of a stretch of open water. The motive force was a falling weight whic

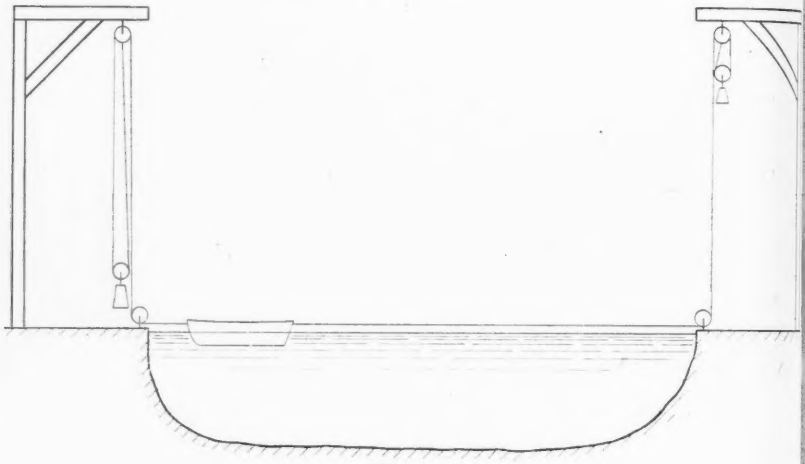


Fig. 7.

Diagrammatic arrangement of Frederik Henrik Chapman's ship tank.

Length 74 ft.

Models 28 ins. long × 8 ins. beam.

acted through a system of pulleys and a smaller retarding force acted on the stern of the model to prevent yawing. The time to travel a known distance was recorded and from these observations it was possible to judge one form against another. The length of run was 74 ft. and the models were 28 in. in length and 8 in. in beam. At this time no laws had been formulated to correlate model and full scale results, and it was left to William Froude to produce his well known Law of Corresponding Speeds and associated data.

Froude did some outstanding work on his tank at Cockington and it is sufficient to say here that his principles of test are employed to this day.

Description of Seaplane Tank.

Most seaplane tanks employ the same basic principles of construction and operation. Differences exist in the methods used to measure forces, etc., and it is not easy to give a casting vote in favour of any one method. It is proposed

therefore, to give a brief description of the Short Tank as it has given complete satisfaction for the type of work carried out.

The tank consists of a long concrete channel filled with water and having straddled across it a travelling carriage which runs on rails extending along the top of the walls.

Fig. 8 shows a general view of the tank and carriage. The electrically driven carriage derives its power from trolley wires running along one side of the tank and the carriage is equipped with an observational side seat and photographic positions.

Fig. 9 gives a diagrammatic view of the model support and recording apparatus.

A model is made of mahogany or some other suitable timber to represent, to some convenient scale, the flotation unit under consideration. To the model is

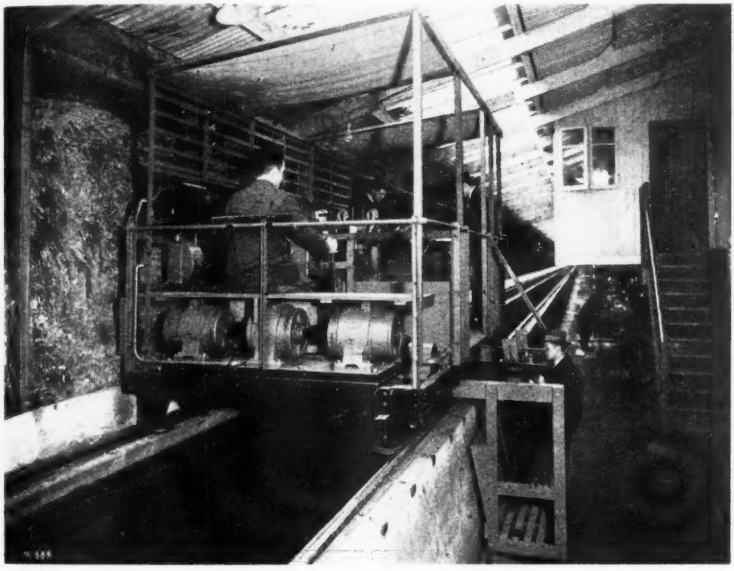


FIG. 8.
Short tank.

fixed a light streamline frame (A) carrying adjustable streamline lead weights which, when suitably positioned, enables the model to be balanced about a transverse exis, (B) corresponding to the centre of gravity of the complete full scale aircraft. The model is then suspended on the frame (C) which is free to swing, within limits, on knife-edged bearings, (D) attached to the inner sides of a frame (F) which is free to slide in vertical guides. By means of the weights (J) connected to the sliding frame by fine wires passing over the light pulleys (H), the model is made to float at the correct displacement. Then to the swinging frame, weights (E) are added to counter-balance the inertia forces on the flotation unit while the tests are being made and a corresponding weight is added to the weights (J) to keep the displacement correct. At the commencement of each test run weights representing wing lift for any particular speed and trim are added to the weights (J).

A long tow rod (K), shown broken, has one end connected to the model at a point corresponding to the airscrew thrust axis and the other end to an arm clamped to a calibrated torsion rod.

The flotation unit, under the action of the water forces, pulls the tow rod back and twists the torsion rod. The degree of twist is magnified up by suitable linkages and converted into linear movement on the face of a revolving drum, turned by a drive from the carriage wheels. The linear movement represents, to some scale, the total model resistance and by applying a suitable scale factor the full scale water resistance of the flotation unit is obtained. An electrically controlled timing apparatus, working in conjunction with the drum, enables the carriage speed to be measured very accurately.

The parallel link system (L) enables the model trim and rise to be measured during the runs.

The inset portion of the hull stern shows the apparatus used to measure the forces required to trim the hull at high speeds. The apparatus consists of a vertical rod attached to a torsion rod system which works in a manner somewhat similar to that of the resistance recording apparatus.

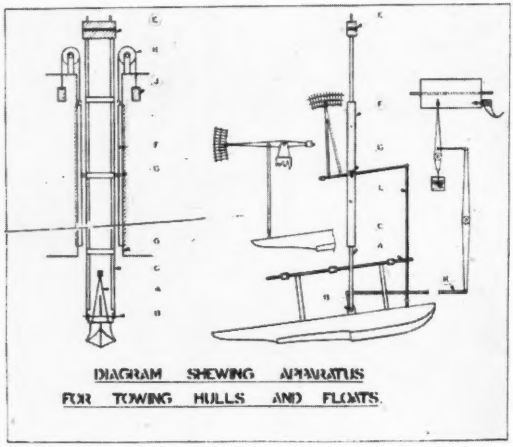


FIG. 9.
Model towing apparatus.

OBJECT OF TANK TESTS.

It is necessary that the tank should supply as much information as possible to the designer so that no design aspect remains a matter of conjecture until the seaplane has flown. The chief information a tank can supply is:—

1. Water resistance during take-off.
2. Attitude of hull during take-off.
3. Trimming moments at high speeds.
4. Dynamic longitudinal stability.
5. Static and low speed transverse stability.
6. Water clearances.
7. Take-off time and run.

The order given should not be taken as an indication of the relative importance of each item.

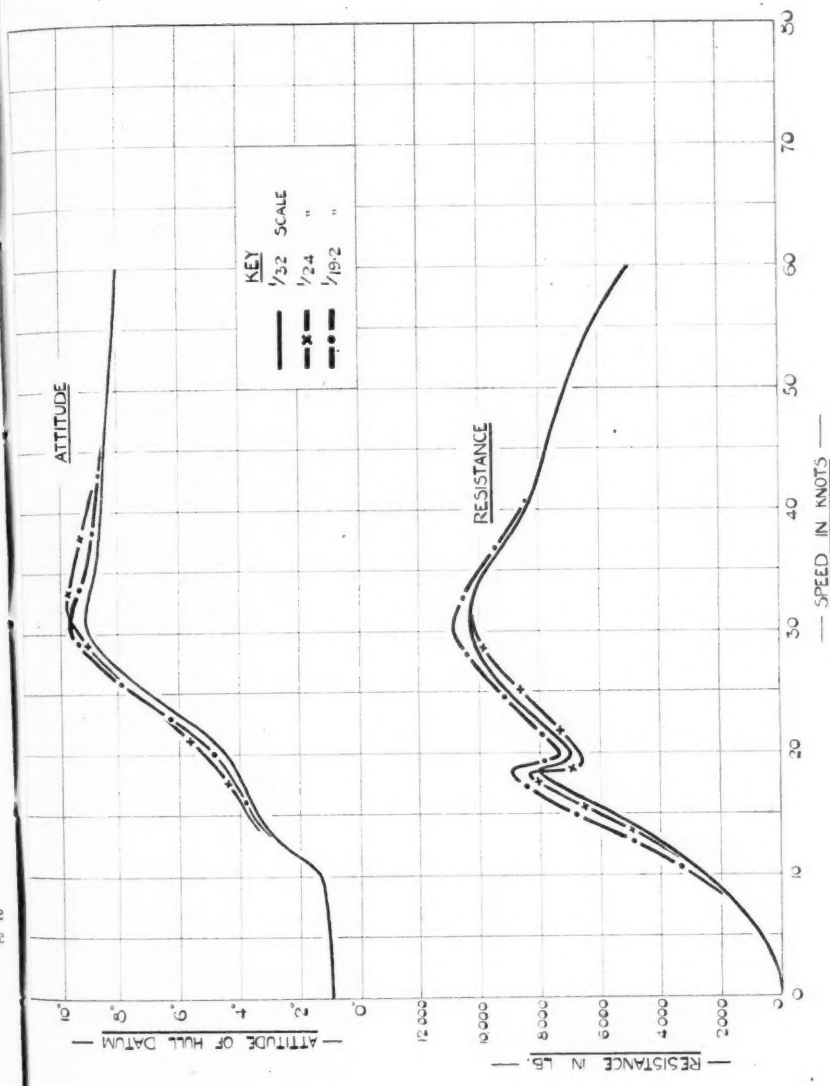


FIG. 10.

Comparison of results on different scale models.

1. *Water Resistance During Take-off.*

The resistance to motion experienced by a vessel moving on the surface of the water is due to (a) wave and eddy making, (b) friction between the vessel and the water, and (c) air forces on the structure above the water.

It is not possible to run a model at any one speed and fulfil the conditions of similarity in wave and eddy-making resistance and skin friction resistance. The model speed of the former is obtained by dividing the full scale speed by the square root of the linear scale, and that of the latter by multiplying the full scale speed by the linear scale, assuming that the kinematic viscosity is the same for both model and full scale.

As an example consider a model of linear scale 1-16th. For wave and eddy-making similitude this model would be run at one-quarter full scale speeds, and at 16 times the full scale speeds for skin friction similitude. Therefore, in tank work, the model is run at speeds correct for wave and eddy-making similitude. At such speeds Froude's Law of corresponding speeds holds and a statement of this Law is:—

"At full scale speed the full scale resistance is given by the model resistance $\times$ (linear scale)^3 when the model speed is full scale speed $\div$ (linear scale)$^{\frac{1}{2}}$."

The model resistance includes forces due to wave and eddy-making, skin friction and air. In ship tanks it is customary to calibrate the apparatus for air resistances and to make an estimation from existing experimental data of the skin friction so that their sum can be subtracted from the total and the remainder scaled up on Froude's Law to give the full scale wave and eddy-making resistance. The total full scale resistance is then obtained by adding to this an estimation of the full scale skin friction resistance and air resistance. These estimations are usually based on experimental data produced by Froude and others.

This procedure is not usually followed in seaplane testing because the estimation for skin friction is unreliable owing to the peculiar and rapid changes of wetted area during the take-off. Thus, it is customary to scale the recorded resistance, less air resistance, on Froude's Law which is another way of saying that, any forces due to skin friction are assumed to be proportional to the (speed)^2 and not to the power found by experiment to be less than 2. This procedure has been found to be reliable on hulls which plane properly but it may produce misleading results on hulls that do not.

The results are influenced by model size and tank boundary effects. The model size is governed by the limiting speed of the carriage which, in the case of the Short Tank, is 10.5 knots. It sometimes becomes necessary to make small models to explore the higher corresponding speed ranges. The results obtained on these small models are not very reliable and they must be judged accordingly.

Fig. 10 shows a plotting of resistances and attitudes obtained on three different scale models representing a flying boat weighing 50,000 lb.

Differences exist around the hump speed but good agreement holds in the planing range which would indicate that Froude's Laws hold at planing speeds.

Experiment has shown that the model length should not exceed the tank width in order to eliminate the tank wall effects.

The influence of the tank bottom is not open to an easy statement because in full scale seaplanes operate from water of varying depths. Most model tests are made at a depth corresponding to 72 ft.

The resistance of a model is measured at various constant speeds and it is obvious that these conditions do not hold in full scale where the boat is accelerated off the water. It is known that accelerated motion increases the resistance, especially under large accelerations. This effect is somewhat minimised in these days of heavily loaded seaplanes because of the corresponding decrease in acceleration.

It is apparent from the foregoing that it is difficult to produce reliable estimates of resistance and it is sufficient to say that when good agreement has been found to exist one is loath to make a change in the testing technique. In any case, any supposed refinement is accompanied by estimations which destroy the simplicity which is so necessary, because a tank should be looked upon as a handy tool rather than as an instrument which has to be carefully handled because of its frailty.

2. *Attitude of Hull During Take-off.*

The attitude or angle of trim of a hull changes throughout the take-off and on modern British hulls the greatest change is approximately 8°. This change in attitude is due to changes in the nature and the type of forces acting on the hull which operates from a static to a flying condition in a few seconds.

At low speeds the forces on a hull can be assumed to be due entirely to buoyancy forces. Therefore, under these conditions, the attitude is determined by the underwater shapes and the disposition of the weight. With increase in speed the buoyancy forces become predominantly planing forces and the attitude is largely determined by the planing bottom shapes and their general disposition relative to the centre of gravity of the seaplane. At speeds where true planing takes place the general layout of the air structure has an important influence on the attitude because the degree of lift taken by the wings affects the proportion of the weight carried on the hull which produces a sympathetic change in attitude. The tail plane setting can influence the attitude at these speeds but, in general, the effect is small. Normally, the airscrew thrust centre is above the centre of gravity of the seaplane and this produces a nose-diving moment and corresponding decrease in attitude. Contrary to general belief the vertical position of the centre of gravity has little influence on the attitude although other design requirements call for a low position.

Other factors influencing the attitude are slip-stream effects, " ground effects," flaps and acceleration.

From tank tests it is possible to obtain the attitude of the hull throughout the take-off so that the wing setting may be selected to give a satisfactory take-off and flying condition. It is obvious that this setting is a compromise. If the wing was put on at a large incidence to relieve the load carried by the hull during the take-off then, when flying, the hull would point nose down in flight, with a consequent reduction in aerodynamic efficiency. The use of wing flaps of the Gouge type make it possible to set the wing on the hull at an incidence more conducive to aerodynamic efficiency.

It has been found that the attitudes obtained from a model exceed, at some speeds, those obtained in full scale. The greatest difference is found at the hump speed. These differences can be put down as being due to inertia, absence of slip-stream, absence of air structure, scale effects and air forces on the model structure.

When judging the behaviour of a model these differences have to be borne in mind.

3. *Trimming Moments at High Speeds.*

At speeds above the hump the aerodynamic forces become predominant and the pilot can, within limits, change the attitude of the hull by suitable elevator control. Under normal take-offs the British flying boat can be flown off with the stick neutral, but under some conditions, say overloading, it becomes necessary to apply elevator control to get the best results.

From tank tests it is possible to tell the resultant effect on the resistance and general running behaviour of the hull under various elevator moments.

4. *Dynamic Longitudinal Stability.*

In the early days of seaplane development the important thing was to get the seaplane air-borne and any longitudinal instability on the water was accepted as an evil of secondary importance. In fact some seaplanes were purposely made unstable by elevator control in order to get off sooner. However, in these days of wing flaps and increased engine powers the take-off has become relatively simple and the stability on the water at high speeds has become of paramount importance. With the increased wing loadings in use to-day the flying boat has to operate at higher speeds on the water and it can be seen that any longitudinal instability at these high speeds is associated with danger.

The designer must, therefore, make certain that the flying boat will be stable throughout the take-off or be free from porpoising, as it is commonly called. Theoretical investigations into the cure and cause of porpoising are incomplete and the designer has therefore to rely on the predictions of a tank and full scale experience.

Many types of porpoising exist but it usually causes the boat to take up a violent longitudinal oscillation accompanied by a rise and fall action.

On the Short tank the stability is checked on a wooden model of the hull which possesses a pitching moment of inertia in excess to scale of that of the full scale seaplane. It has been found by experience, that such a model gives predictions which possess a factor of safety. Thus, it is said, that a stable model means a stable full scale seaplane. The converse is not necessarily true. Some American type hulls known to be fairly stable in full scale produce a porpoise on the tank. It is worth considering this case. It would seem that the American designers rely, to a large extent, on the tail plane to provide longitudinal stability at high speeds, and this policy can be seen in the short length of afterbody. The British hulls possess what might be called inherent dynamic longitudinal stability, as seen in the long afterbodies. It is interesting to notice that recent American hulls are following the British policy.

The R.A.E. tank employs models equipped with complete air structure which are true to scale weight and inertia. A suitable technique has been evolved for the testing of such models and a very wide range of investigation is possible on such models which are capable of flying.

The following details have an important bearing on the porpoising characteristics:—

Length of afterbody.

Depth of main step.

Location of main step to centre of gravity.

Air structure.

This last detail is interesting. Evidence has shown that a poor aerodynamic lay-out can produce a poor water performance.

5. *Static and Low Speed Transverse Stability.*

It is well known that a flying boat is laterally unstable when stationary or moving at low speeds on the water. Some form of stabilizer is necessary, and the two forms in general use are stubs and wing floats.

Stubs have a few advantages, but experience and recent tendencies by the advocates of stubs show that the wing float has by far the best all-round performance. The fact that floats lend themselves to retraction also enhances their reputation. It would, therefore, appear that the old controversy of stubs versus wing floats is ended.

The size of a float depends on many things and apart from form is determined by:—

(a) Distance of float from hull.
(b) Degree of inherent transverse instability of the seaplane.
(c) Float water clearance.
(d) Float setting to the water.
(e) Wind forces on the seaplane.
(f) Airscrew torque.

In the past, various formulæ have been used to determine the float size and these formulæ were partly empirical and usually possessed an elusive constant. The float size obtained was invariably too great, which, in these days of speed, is undesirable. The method now used is based on a knowledge of the wind forces on the seaplane, the degree of inherent transverse instability and airscrew torque. Thus, by dividing the sum of such moments by the semi-float track, the float size can be determined.

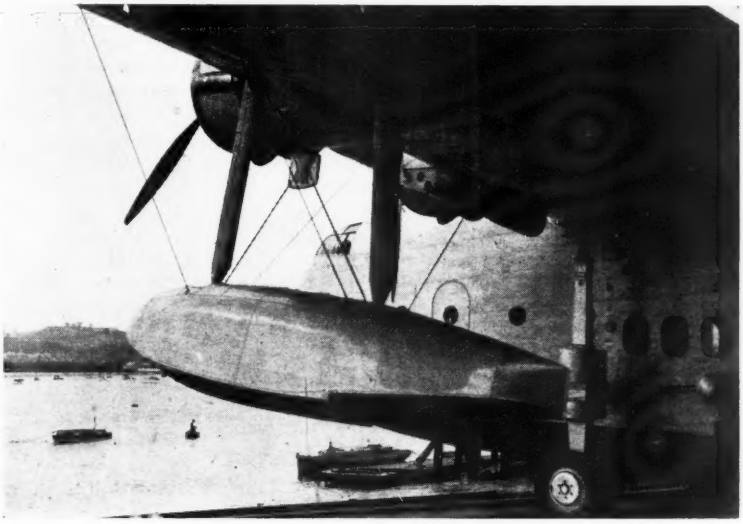


FIG. 11.

Empire boat—wing tip float.

The form of float used depends to some extent on the method of attachment to the wing. One of the best forms, from an air and water viewpoint, is of such a length that wire bracings are necessary to prevent torsional movement. This type is found on the " Empire Boat" and " Sunderland."

Fig. 11 shows very clearly this wire bracing on the " Empire Boat " wing float.

The air resistance of these wires is considerable, and in order to increase the aerodynamic efficiency of the " Lerwick " flying boat they were dispensed with. This forced the designers to fit a float of relatively short length.

The fixed float must be designed to suit the requirements of both air and water. Thus the float must be reasonably streamlined but set on the seaplane at a fairly coarse angle for good water performance. This angle is a compromise. In general it is found that the behaviour of the float on the water improves with increase in angle, which, of course, increases the air resistance of the float when in flight.

In the case of a completely retractable float no attention need be paid to aerodynamic form, but where the float is retracted and housed on the wing at least some portion of the float requires a good aerodynamic form.

Most floats are provided with a vee bottom and a step. The use of a step is sometimes questioned, but the large fixed type of float would appear to require one.

It is possible to tell from tank tests the best form of float to use on a particular seaplane, and the setting necessary for full scale requirements.

6. *Water Clearances.*

The portions of the seaplane in close proximity to the water are liable to receive a buffeting from the water thrown aside by the hull or by waves formed on the surface of the water by natural causes. Therefore, the water clearances of such things as airscrews, flaps and tail planes must be sufficient to ensure that, in full scale, no damage will be sustained.

Tests are made on a model equipped with representations of airscrews, flaps and tail planes, and the water clearances of the components noted at various speeds and water conditions.

The height of wave thrown by a small model exceeds those found in full scale and this, together with the absence of slip-stream, makes the model predictions pessimistic. In these days of hull size reduction, it has become increasingly difficult to say if the water clearances will be satisfactory in full scale, and it is necessary to observe the full scale behaviour of existing seaplanes whenever the opportunity arises.

7. *Take-off Time and Run.*

The time taken by the seaplane to become air-borne should be as small as possible because the longer the seaplane is on the water the more risk it runs of damage. This is especially true in rough water, so the designer must know the time and run to take-off.

The data required to estimate the time and run includes take-off speed, water resistance, air resistance and airscrew thrust. The net accelerating thrust can be determined and the time and run derived from the well known formula

$$P = \frac{Wa}{g}$$

It has been found that the model predictions agree well with full scale values and are usually slightly pessimistic.

Evolution of a Flying Boat Hull.

The tank is supplied with details of the air structure, power, weight and possibly size limitations. It is then necessary to add a suitable planing bottom to the aircraft. If the flying boat does not differ in many respects from an existing successful type it is usual to adapt these hull lines to suit. Sometimes, however, it is desirable to start afresh, to incorporate any marked improvements that have been made in the general research programme, which is always at hand. It is this case which will be dealt with.

A start must be made somewhere and it is usually commenced with the maximum beam at chine. This is a most important dimension as it has a direct influence on the water resistance, draught, planing bottom area, and hull frontal area. The present tendency is towards narrow beam hulls because of aerodynamic improvement and weight saving. With present engine powers and flaps the beam need not exceed .26 $W^{\frac{1}{3}}$ ft.

Where W is the weight of the flying boat in pounds.

In 1933 Mr. Lower[1] gave this factor as .36, which shows that for a given weight a saving of 27.8 per cent. on beam has been made.

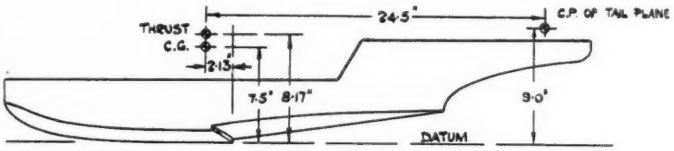
The length of the forebody should be 3.4 × maximum beam.

In 1931 Mr. Gouge[2] gave this factor as 2.75.

From this data it can be shown that the projected plan area of the forebody on a modern hull has been reduced by approximately 35 per cent. for a given weight.

SHORT BROS. EXPERIMENTAL TANK
DATA SHEET

Aircraft : 4-engined Boat Seaplane. All-up Weight : 60,000 lb.
Position of C.G. : 4ft. 3in. forward of step at keel; 15ft. above datum.
Position of Airscrew Thrust Axis : 16ft. 4in. above datum
Position of C.P. of Tail Plane : { 49ft. from C.G. of machine. / 18ft. above datum.



SET-UP OF MODEL

Scale : 1/24th. Attitude of Datum Line when at Rest : 3.6°

FIG. 12.

Data, four-engined boat.

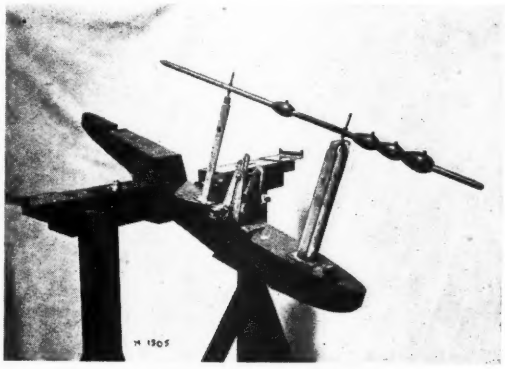


FIG. 13.
Balancing model.

The length of the afterbody should be approximately .9 of the forebody with the keel line set at approximately 8° to the forebody keel at step.

In 1931 Mr. Gouge[3] gave the length as approximately equal to the forebody and this was on a hull having a transverse rear step.

It can be shown that the projected plan area of the afterbody on a modern hull fitted with a knife-edged rear step has been reduced by approximately 30 per cent. for a given weight.

This reduction in planing bottom area, when converted into hull weight reduction, represents a considerable amount and it would seem that this reduction

will go on so that a hull will correspond more closely with that of a land plane fuselage.

Assuming that the flying boat under consideration will weigh 60,000 lb. then by using the foregoing data the hull will have the following dimensions:—

Maximum beam of hull at chine	10.2 ft.
Forebody length	34.6 ft.
Afterbody length	31.2 ft.

The lines are then faired round these critical dimensions to suit the dictates of past experience and any desired modifications.

A model hull is then made of wood to a convenient scale, which in this case is 1-24th. It should be pointed out that the models are made to a great accuracy and finished off with shellac.

The finished model is set up for testing as shown on Fig. 12. It will be noticed that the dimensions given on the diagram are in model inches and they

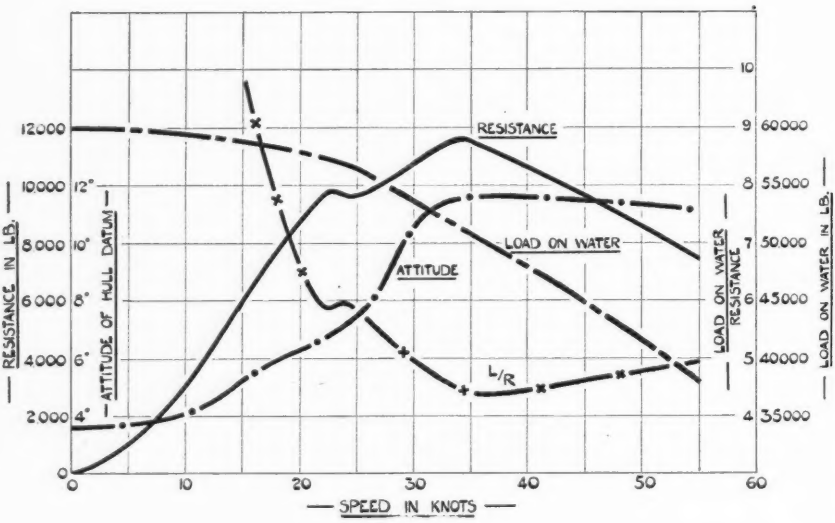


FIG. 14.

Attitude-Resistance-load on water-efficiency curves during take-off.

must be multiplied by 24 to bring them to full scale. The hull datum shown is a line running along the straight portion of the forebody keel and this has been found a convenient datum when comparing results obtained on different hull forms.

The model is towed from the airscrew thrust point which is obtained by running back the airscrew thrust line until it is vertically above the centre of gravity.

Next the model is fitted with a light streamlined frame carrying streamlined lead weights which are capable of adjustment. The model is then balanced about an axis corresponding to the centre of gravity by suitable adjustment to the weights, as shown on Fig. 13.

The model is then suspended from the support gear on the tank carriage and, by means of counter weights, brought to the correct model displacement of $60{,}000/(24)^3$.

At the commencement of each test run an estimation of the total wing lift is made for every condition of speed and trim and is added to the counter weights. The model lift is obtained by dividing the full scale lift by $(24)^3$.

It will have been noticed that the model is not free to roll and yaw, but should any test run show the necessity of representing such conditions on the model it is a simple matter to cater for them.

On a new hull a great deal of experimental work is usually necessary to produce a satisfactory hull form.

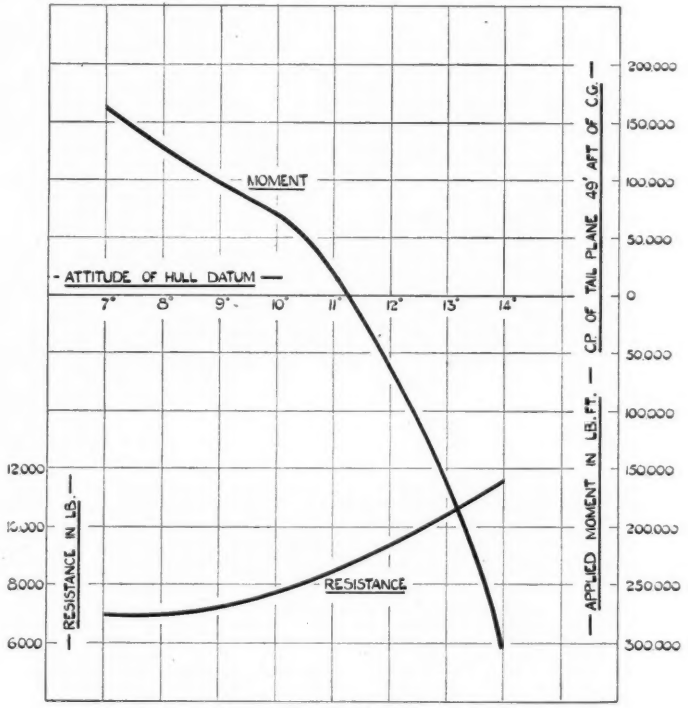


FIG. 15.
"Moment-attitude-resistance" curves.
Constant speed 50 knots.

Fig. 14 shows a plotting of a typical set of results. Four curves are plotted on a speed base and although it may appear confusing it has been found most useful when analysing a set of results.

The resistance curve possesses two humps, the first being produced by the influence of the main step when the hull is in the displacement stage, and the second is at the two-step stage when the resistance value is a maximum and is approximately 1-5th the weight of the seaplane. The efficiency curve, given by the ratio of the load on water to the resistance (L/R) has a minimum value of 4.4 at the hump speed. This ratio provides a convenient way of comparing the performance of hulls, and in 1931 Mr. Gouge[4] gave the minimum value for

efficient hulls as being 5.0 to 5.4. Therefore, the modern hull has a decreased efficiency which is due to the marked attention paid to its aerodynamic features.

The load-on-water curve is interesting. At the hump speed only approximately 14 per cent. of the weight is taken by the wings. At a speed of 55 knots (75 per cent. take-off speed) the weight taken by the wings is approximately 37 per cent. of the total. These facts make clear the work done by a hull and is an aspect which is not always appreciated.

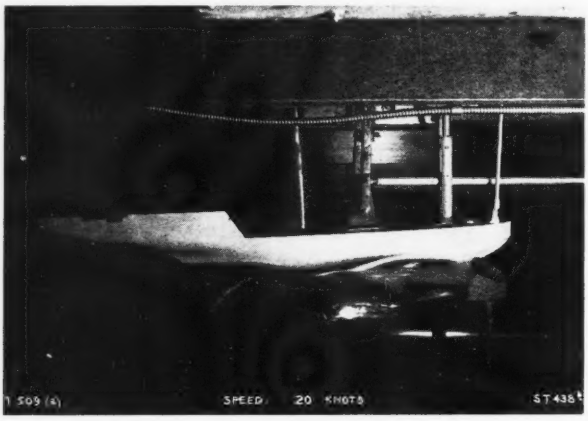


FIG. 16.
Model running 20 knots.

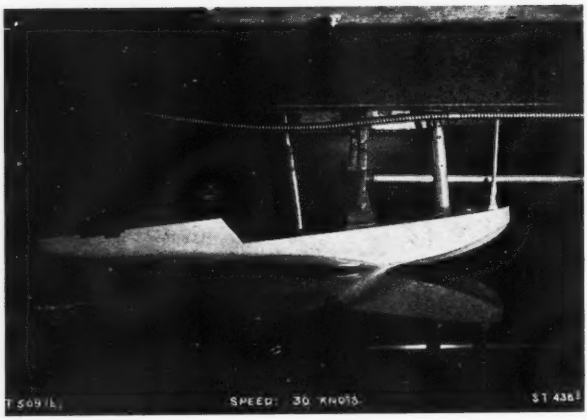


FIG. 17.
Model running 30 knots.

Fig. 15 shows the results of a test made at a speed corresponding to 50 knots to ascertain the degree of elevator control which the pilot can apply. It should be pointed out that the full scale moments are obtained by multiplying the model moments by $(24)^4$. It will be noticed that the hull is more easily trimmed

forward, and when this is done the resistance shows a decrease. Thus it would appear that a finer trim would produce a better take-off. This is usually true up to a reduction in attitude of approximately 2^0, but beyond this the gain is lost because of the decrease in wing lift. In any case, the running of the hull at fine trims is undesirable because of the possibility of porpoising, together with the danger of striking large waves at a point near the bows, which would result in a dangerous lurch.

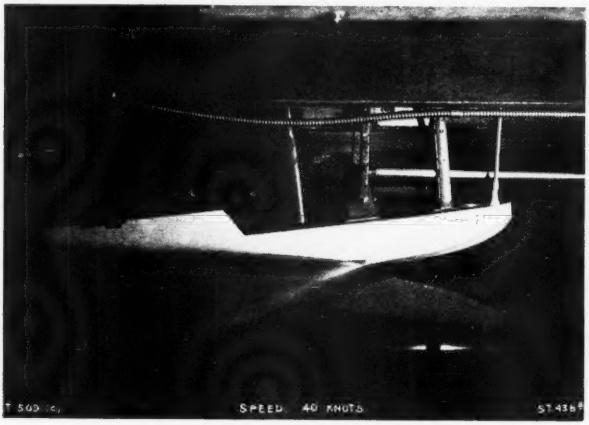


FIG. 18.
Model running 40 knots.

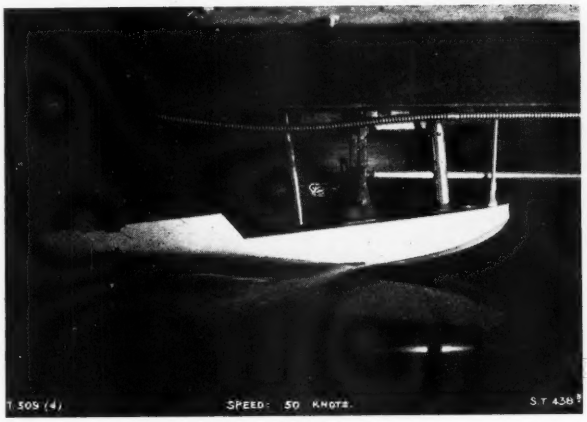


FIG. 19.
Model running 50 knots.

Figs. 16, 17, 18 and 19 show the model running on the tank at speeds corresponding to 20, 30, 40 and 50 knots.

At a speed of 20 knots the wave thrown by the forebody takes on the form of a sheet at its extremity, but in full scale spray would be formed. This sheet

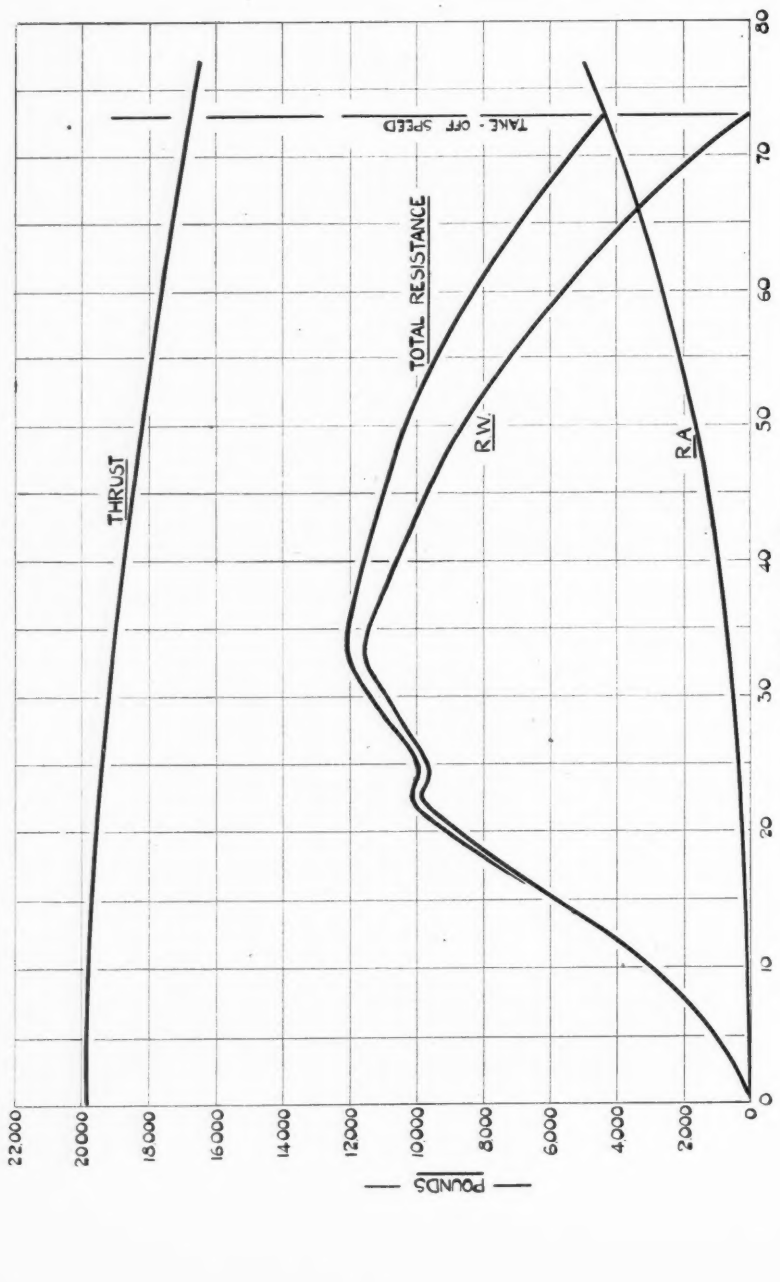


FIG. 20.
Take-off data.

formation is largely due to surface tension, but at higher speeds the resultant waves do resemble more closely those found in full scale.

Tests are made to ensure that the water clearance of the airscrews, flaps and tail planes is sufficient and any adjustment made as thought necessary.

It is usual to carry out complete tests on the type of wing float to be fitted and these include the testing of a reasonably large model float in a manner somewhat similar to that of a hull. The chief points to aim at in wing float design are good rise qualities, good recovery in rough water, and a small water resistance. The tests on the float are concluded by attaching a pair of wing floats to a hull of the same scale set up free-to-roll and, if necessary, free-to-yaw. From these tests it is possible, by the application of suitable moments, to determine the behaviour of the floats on the seaplane in rough water, cross winds and turning.

Fig. 20 shows a plotting of the take-off data. The estimated take-off time was 24 seconds and the corresponding run was 520 yards. In this particular design the take-off would be easy, but in some designs, where the engine power is limited, the total resistance curve will approach very close to the airscrew thrust curve. Under such conditions the estimated results are somewhat uncertain and in general the tank results are pessimistic.

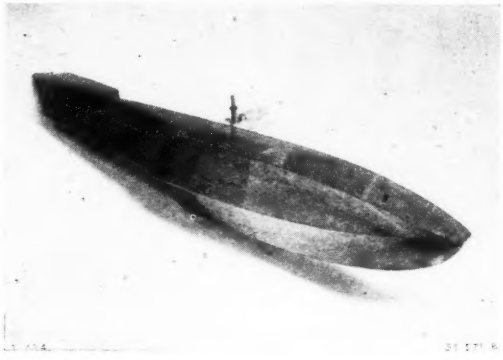


FIG. 21.
Inverted vee bow model hull ST. 571E.

RESEARCH.

A wide field of research is carried out in a seaplane tank and in the case of the Short tank emphasis is placed on work which will produce results of direct practical use to the designer whose job it is to produce successful seaplanes.

In order to indicate one aspect of the research carried out it is decided to deal with a project which was considered a few years ago.

On flying boats which are called upon to operate at fairly high flying speeds it is an advantage to make the hull volume as small as possible. In order to reduce this volume the possibility of reducing the length, depth and breadth was considered. After some work had been carried out it was found that only a marked change to the bow shapes would produce a saving in hull volume. This decision was made in the light of past experience and present flaps and engine powers, and will, of course, be subject to revision in the future.

The modification resulted in a hull having inverted vee or sled bows. Fig. 21 shows a view of the tank model looking towards the underside of the bows. It

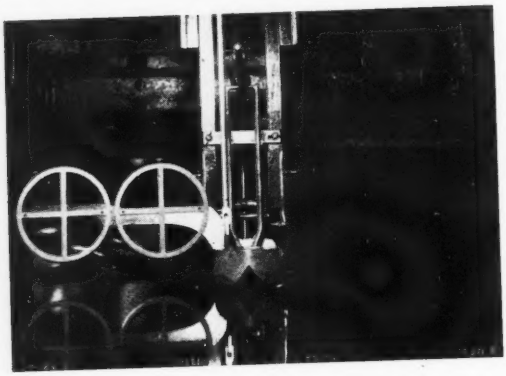


FIG. 22.
Inverted vee bow model running 10 *knots.*

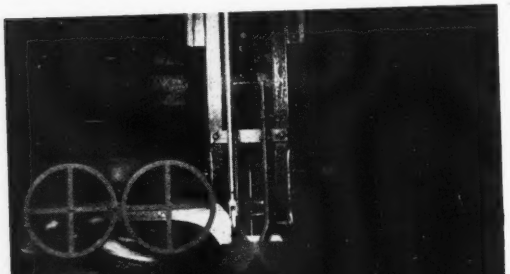


FIG. 23.
Inverted vee bow model running 15 *knots.*

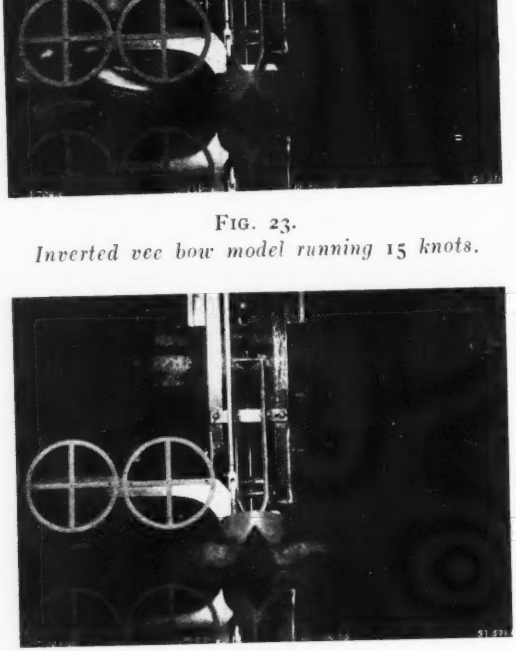


FIG. 24.
Inverted vee bow model running 20 *knots.*

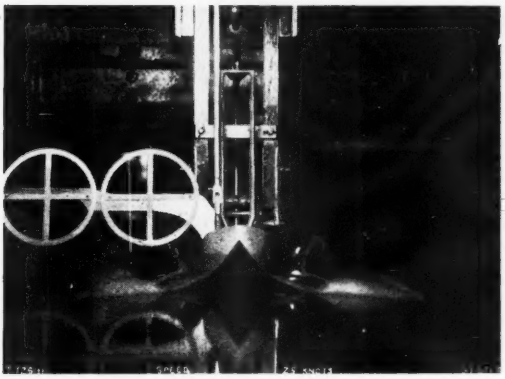


FIG. 25.
Inverted vee bow model running 25 knots.

can be seen that the keel runs up inside the bottom near the bows and that the chines near the bows are much lower than on normal hulls.

After a few modifications it was found that the bows produced hardly any transverse waves, which made it possible to decrease the airscrew water clearance and so produce a reduction in hull side area.

Figs. 22, 23, 24 and 25 show the model equipped with representations of the starboard airscrews, running on the tank at speeds corresponding to 10, 15, 20 and 25 knots. The airscrews are attached in their lowered position which would represent approximately a drop of 1 ft. 6 in. on a fairly large flying boat.

It is interesting to notice that at a speed of 20 knots only a small flurry of water is visible, whereas on a normal hull the wave height is considerable, and it is at this speed that the water clearance of the airscrews is a minimum on a flying boat like the "Sunderland."

At the speed of 25 knots the sled bow is almost out of the water and the influence of the normal vee bottom has produced the split form of wave. Although this condition appears critical the peak of the wave forms aft of the airscrew disc, and is therefore satisfactory.

The hull was tested in a wind tunnel against a corresponding normal hull form and the results showed that the modified hull possessed a higher resistance and would require an increased tail plane volume for a given degree of control.

From considerations of construction and operation the modified bow was undesirable. The structure weight at the bows would be increased and the interior arrangements complicated. It appeared, therefore, that the fitting of the sled bow would be undesirable and the project was not carried any further.

FURTHER WORK.

It has not been possible to describe all the work carried out, but the following can be done:—

(a) Pressure distributions on hull and float bottoms.
(b) Flotation of hulls and floats whose bottoms are open to the sea.
(c) Tests on aerodynamic bodies completely immersed in water.

CONCLUSION.

In conclusion, I hope that I have succeeded in showing the importance of a tank to the seaplane designer.

It will be noticed that a tank possesses a number of shortcomings which have to be made good by personal judgment. This personal element is undesirable but by using plenty of common sense, and by absorbing all the full scale experience possible this element becomes a part of the general scheme which goes towards the production of a successful seaplane.

I am indebted to Messrs. Short Bros., and in particular to Mr. Lipscomb, for permission to publish this paper, which contains data obtained whilst in the service of the firm.

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2, 3.—A. Gouge, "Design and Construction of Flying Boats." Inst. Eng. and Shipbuilders in Scotland, 24th March, 1931.
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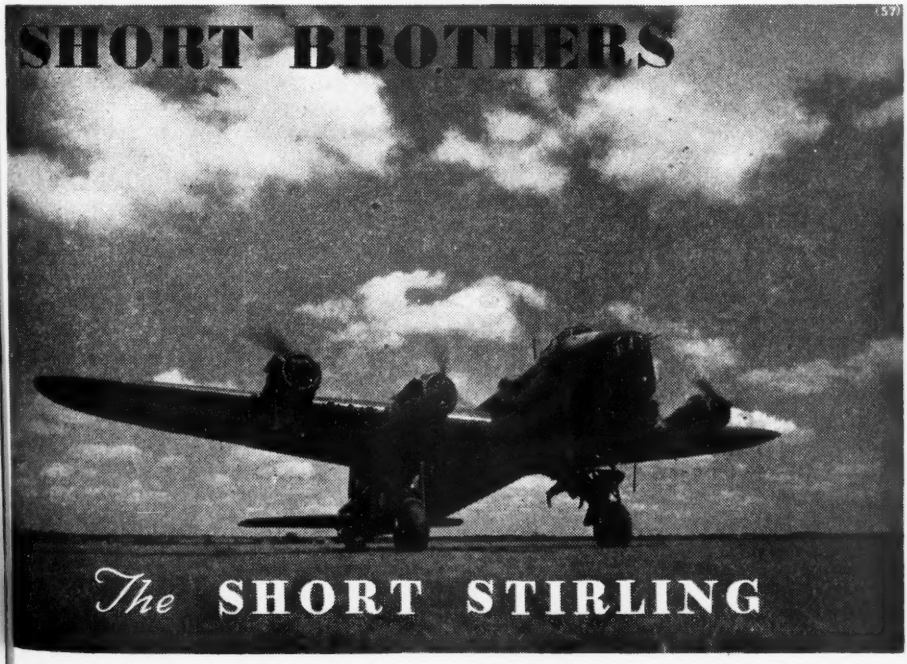
FAIREY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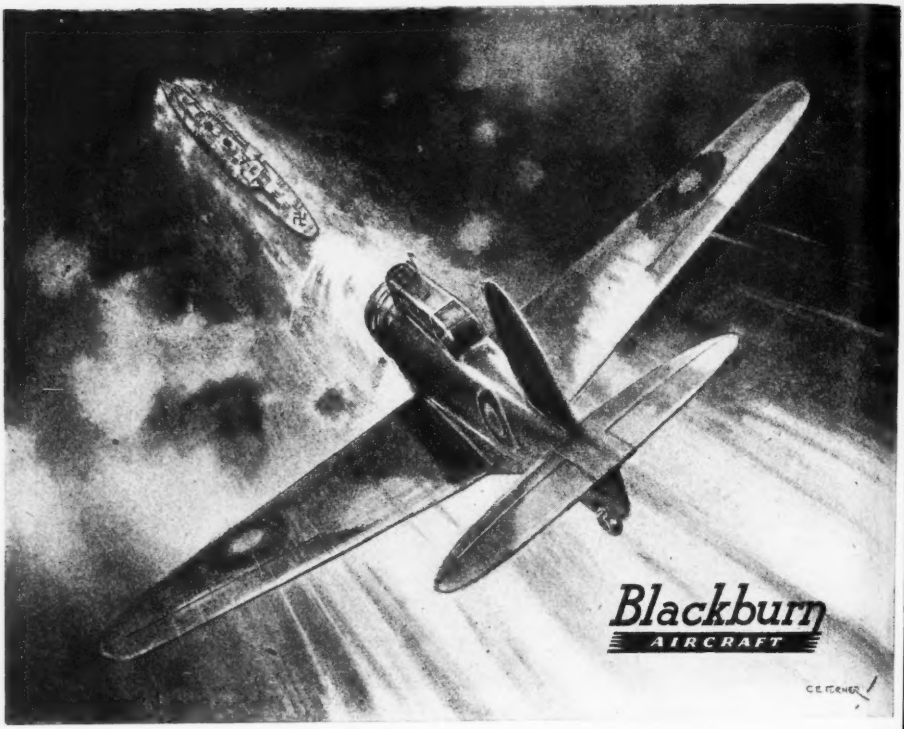

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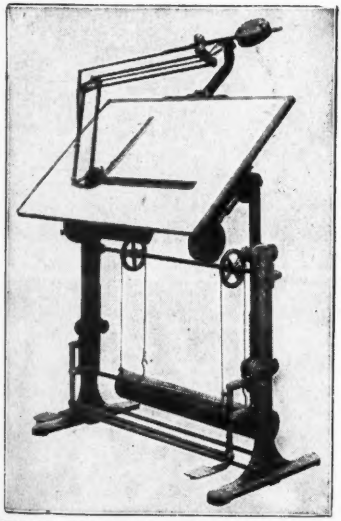

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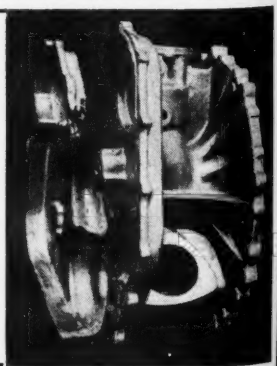

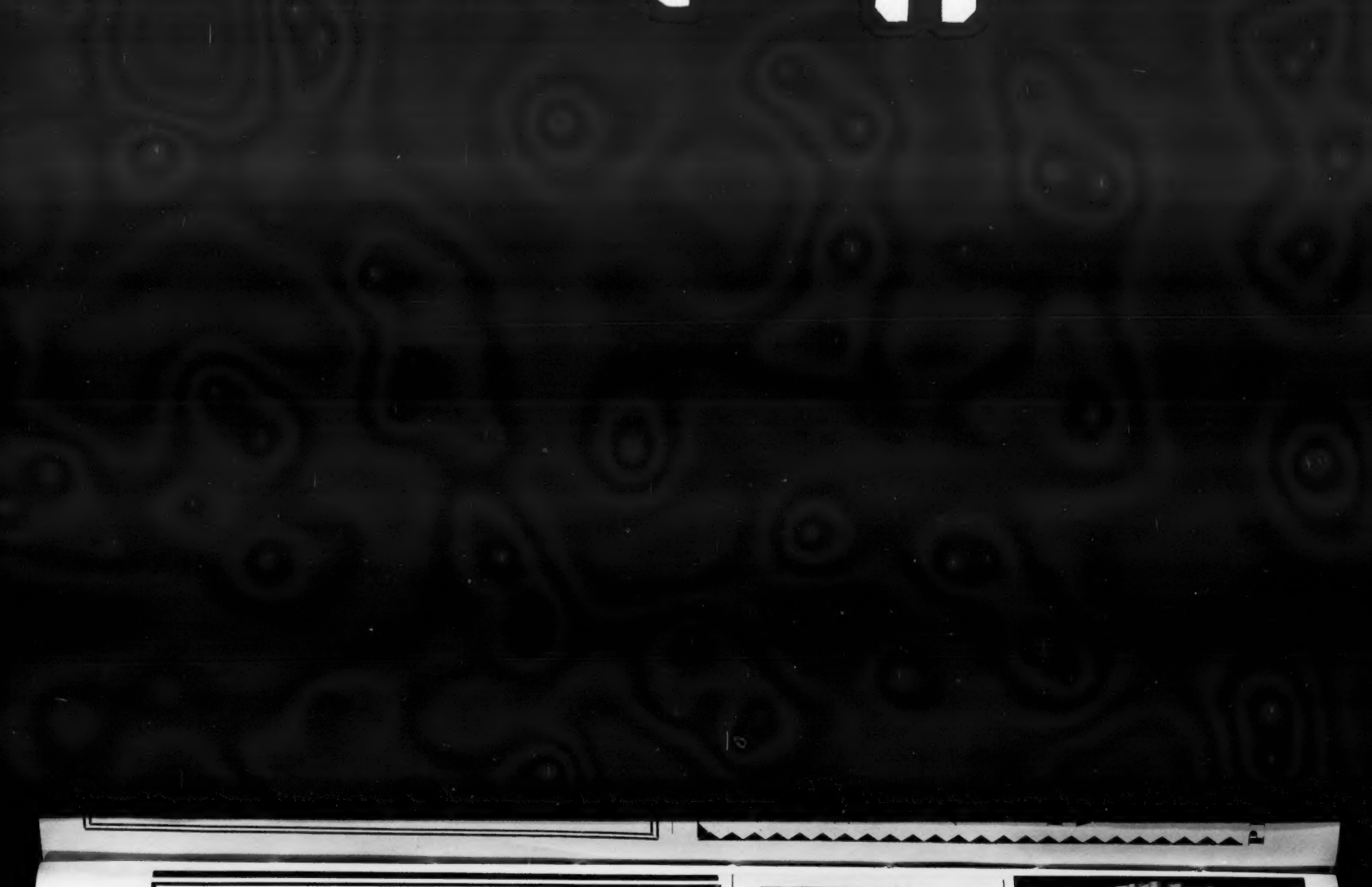

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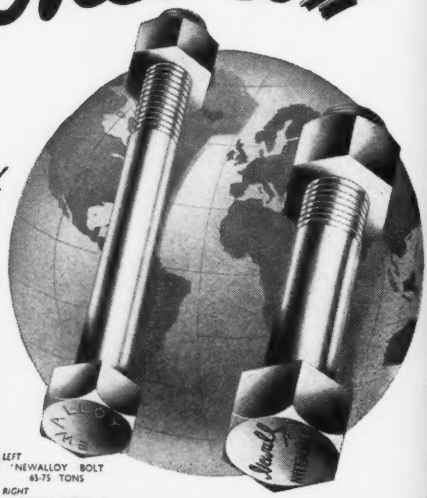

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